

International High- Performance Built Environment Conference – A Sustainable Built  
Environment Conference 2016 Series (SBE16), iHBE 2016

## Temperate climates, warmer houses and built fabric challenges

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### Abstract

The recent enhancements of the National Construction Code have reduced the amount of energy required to heat and cool Australian homes. To date, the result of these changes, within Australia's temperate and cool-temperate climates, is generally warmer internal temperatures. However, many of these warmer homes are presenting condensation and mould. This is demonstrating a general non-awareness of vapour pressure management within the Australian design and construction professions. This paper discusses research from the architectural and medical science disciplines. The paper identifies a significant gap in appropriate building regulation and building science knowledge within this field in Australia.

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Peer-review under responsibility of the organizing committee iHBE 2016

**Keywords:** Condensation; mould; building regulation; vapour management; human health

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### 1. Introduction

The recent enhancements of the Australian National Construction Code have reduced the amount of energy required to heat and cool homes [1-3]. A mixture of market demand [4, 5] and further enhancements to the thermal performance regulations [6, 7] will further increase thermal comfort within new houses in Australia's diverse range of climate types. To date, the result of these changes, within Australia's temperate and cool-temperate climates, is generally warmer housing [8]. The warmer internal conditions are due to the combination of a more thermally effective built fabric[9-11], the relatively low cost of energy and the ready access to after construction heating and cooling appliances.

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However, many of these warmer homes are presenting new problems. Initially, it was thought that these problems were only occurring in some houses in some climates [12, 13], however recent research has identified problems occurring in all Australian climates [14]. The appearance of condensation and mould within new homes has become significantly more apparent with many new home owners contacting their Building, Building surveyor and the State Government Building Regulator [12, 15]. In many instances mould has been present within six weeks of new house occupation. In late 2015, the individual jurisdiction (state) members of the Australian Building Codes Board (ABCB), elevated their concerns, which led to the ABCB requesting a quote for services, namely; Scoping study of condensation in residential buildings.

A deep review of condensation problems in new buildings, conducted by the University of Tasmania [12] established a general non-awareness of vapour pressure management within the Australian design and construction industries. This was further supported by conversations with Building Regulators and building material manufacturers. Similarly, there is a growing body of medical evidence from patients presenting themselves with immunology and allergy conditions in most Australian climates. Deeper medical investigations have revealed the presence of mould within homes and/or workplaces [16-18].

This paper discusses research from the architectural and medical science perspectives. The architectural science perspective will discuss recent experiences of mould and condensation in new houses in Tasmania, Australia generally, and international regulation. The medical science perspective will discuss experiences from a few distinctly different climates. These two perspectives will highlight a significant gap in appropriate building science knowledge and awareness within this field in Australia. This paper will also include recent recommendations to the Tasmania Building Regulator.

## **2. Building regulation and energy efficiency enhancements**

In response to the global awareness of climate change, the Australian government commenced the development of legislation to reduce greenhouse gas emissions [19-21]. The measures included regulations to reduce the amount of energy that may be required to condition residential and commercial buildings [22, 23]. The first white paper concerning this topic was instigated in 1997 after the Kyoto Earth Summit. Research from this time indicates that Australia's existing housing stock was starting from a low base when compared to the EU and parts of the US [24-26]. The Nationwide House Energy Rating Scheme (NatHERS) was established and in co-operation with state governments and industry established climate based thermal comfort levels, internal load parameters and star-bands for Australian housing [27]. During this process, it was established that most new homes constructed in 1998 were between 1 Star and 3 Stars [26, 28]. Initially, the primary aim of the Building Code of Australia energy efficiency requirements were to reduce greenhouse gas emissions by minimising the amount of heating and cooling required for human comfort derived from the burning of fossil fuels.

Based on this new star based metric it was agreed that a minimum performance rating of 3.5 to 4 Stars would be adopted by all jurisdictions in 2003-2004 [23]. The minimum thermal performance requirement was upgraded to 5 Stars in 2006 [29], and to 6 Stars in 2010 [2]. The change from no or minimal built fabric thermal performance regulations in 2002 to the 6 Star requirement of 2010 has had a significant impact on material choices and construction methods in Australia's cooler and hotter climates. It should be noted that the focus on Star Ratings has evolved due to the National Construction Code (NCC) including no quantitative requirements for greenhouse gas emissions [30]. Each step increase in the regulations since 2003 has required higher levels of floor, wall and roof space insulation combined with a better average conductivity U-Value for glazing. Since the adoption of the 6 Star requirement, most jurisdictions have identified a shift from built fabric thermal resistance methods to NatHERS Star Rating based Deemed-To-Satisfy designs. However, to comply with these changes, many building designers, building surveyors and builders have simply amended the thermal resistance R-Value of the insulation system, often having no deep understanding of built fabric system thicknesses [12]. Additionally, there has been an increasing requirement within the NCC for building sealing, describing actions for service penetrations, apertures and building infiltration. In response to these requirements, there has been a growing use of building wall wrap and roof sarking systems.

In response to increasing, and horrific, bushfires, a new Australian Standard was developed, namely; AS3959: Construction of buildings in bushfire-prone areas. As a part of this process of protecting house occupants and

building assets, in addition to non-urban buildings, many houses located within 100 metres of a suburban fringe were classed as being in a bushfire prone area. The general focus of the standard is to:

*“improve... resistance to bushfire attack from burning embers, radiant heat, flame contact and combinations of the three attack forms” [31]*

This standard further increased the perception that buildings must be built ‘tight’, without a deeper understanding of what tight might mean within the deeper mix of building physics.

### 3. Is there a condensation and mould problem

#### 3.1. The Tasmanian experience

In response to a growing concern from new home owners, the Tasmanian building regulator (Building Standards and Occupational Licensing, Department of Justice) initiated a research project with the University of Tasmania. The project which commenced in 2014, was to explore the presence of destructive condensation within new Tasmanian homes. To the concern of government and the university researchers, the telephones ‘rang hot’. Owners of old homes, new homes and older homes with renovations, builders, building surveyors and building designers were making contact, raising concerns about surface, interstitial and roof space condensation and significant mould growth. In response to these concerns, the university research team provided general advice via the telephone and site meetings, and completed a detailed assessment of three new homes which presented excessive moisture in subfloor, internal rooms and roof spaces.

The analysis of the case study houses included the detailed environmental measurement of subfloor, conditioned room and roof spaces, an analysis of approved architectural construction documentation, construction practices and mould sampling. The detailed measurement collected temperature and relative humidity data from subfloors, conditioned rooms, the roof space and site. Additionally, air pressurization tests were completed for all zone types and surveillance cameras were installed within roof spaces to collect image based data of condensation occurrences. At each site visit photographs were taken of condensation as shown below in Fig. 1 to Fig. 3.



Fig. 1. Excessive condensation and mould on aluminium window.



Fig. 2. Condensation forming around downlights.



Fig. 3. Condensation forming in roof space.

The detailed measurement established empirical data documenting areas within the built fabric that had very high levels of moisture and saturation, as shown in the psychrometric charts of Fig. 4 and Fig. 5. In Fig. 4 the Orange/Yellow = Level 2 living room, the Green = Site conditions, the Red = Level 2 mid roof space and the Blue = Near Level 2 roof space sarking. This chart is typical of the several months of data which was collected and highlights some distinct patterns, namely:

- The temperature within the Level 2 living room is always considerably warmer than the site air temperature. This is due to the home owners thermal comfort expectations and has been achieved through the use of a reverse-cycle air-conditioner on a 24 hour, 7 day a week basis.

- The conditioning pattern created a very significant and constant vapour pressure driver from the level 2 rooms to the external walls and roof space.
- The flow of vapour into the roof space is further supported by the number of holes in the ceiling fabric caused by the use of down lights, cavity sliding doors and the bathroom ventilator.
- It can be clearly seen that the environmental conditions near to the sarking were nearly always at saturation temperature, causing the constant presence of significant condensation on the sarking material.

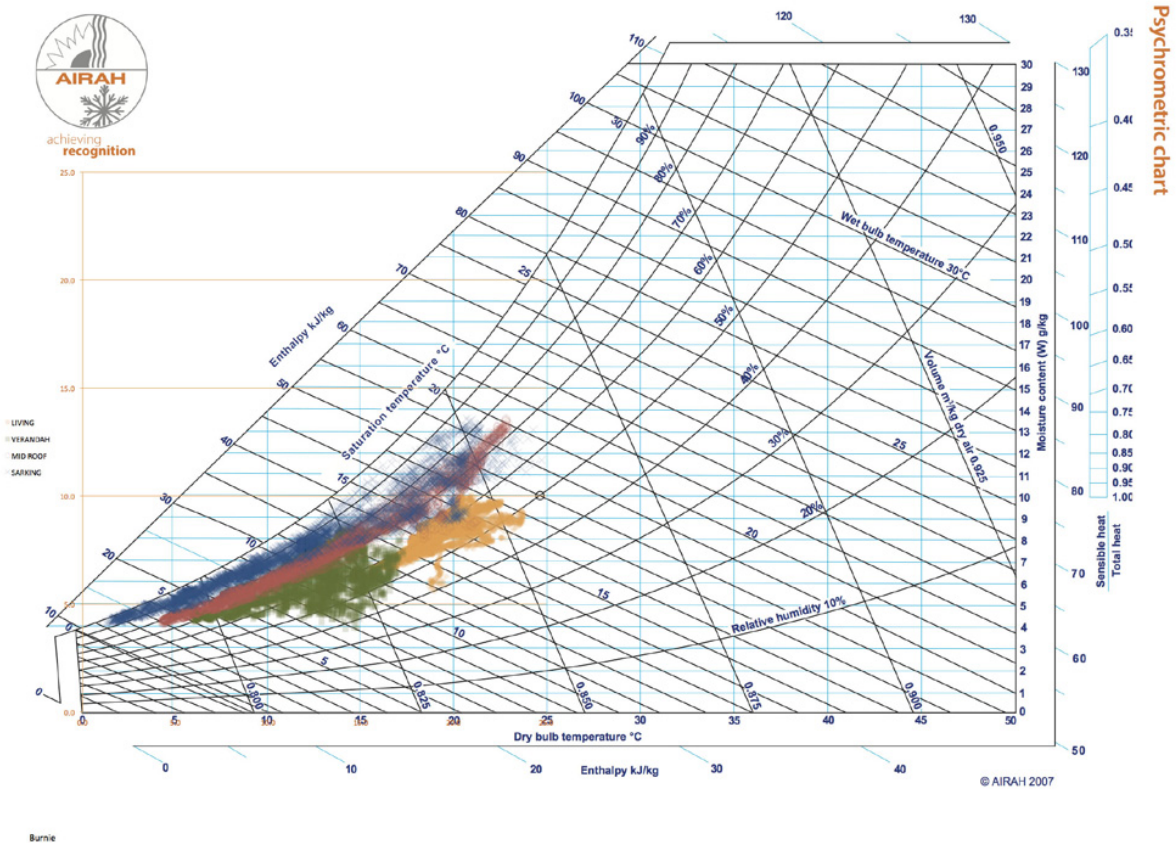


Fig. 4. Burnie psychrometric chart.

Fig. 5, below, shows one of the psychrometric charts for a new home in Molesworth. In this graph the Red = mid-roof space, the Blue = sarking, the Orange = living, and the Green = site conditions. This psychrometric chart, documents that the mid roof temperature and humidity were both higher than site conditions. This was caused by the additional energy and moisture created within the house through human occupation and heating. The sarking conditions are based on the measured sarking temperature taken with the concurrent measurement of mid-roof absolute humidity. Where the data extended beyond the saturation curve (i.e. on the left of the 100% RH curve) condensation can be expected, and it occurs frequently in this graphical analysis and in corresponding time-lapse photographs from this roof space. The constant high moisture environment resulted in regular data logger resistor failure. The high condensing environments in the measured houses roof spaces proved to be a challenging condition for the relative humidity sensors and data logging equipment.

Fig. 6 below, shows a sample of the measured temperatures for the Molesworth House recorded from 5-16 Sep 2014. This graph shows some regular flat-lining of the minimum temperatures indicating periods when the moisture



around the temperature sensors was freezing. The lower graph is an analysis of likely dew-point temperatures. Whenever sarking temperature is below dew-point (i.e. when  $dT$  [sarking T – sarking DP] is a negative value) condensation can be expected on the inside surface of the sarking. During this eleven day example, condensation was likely to form on the inside surface of the roof space sarking, and this was supported by the surveillance camera imagery. However, due to the regular high moisture content of the roof space, condensation was occurring during daytime and evenings which is not evident from the dew-point analysis. The occurrence of condensation and moisture was not limited to roof spaces. Fig. 7 below shows expanded window reveals in a 8 week old residence. This occurrence, and other obvious forms of excessive condensation caused the home owners to contact the project Building Surveyor. Fig. 8 below shows what the research team found when the external wall cladding and building wall wrap were removed. The wall batt insulation, and timber studs, bottom plate, joist and bearer were all sodden, with timber moisture levels greater than 17%.

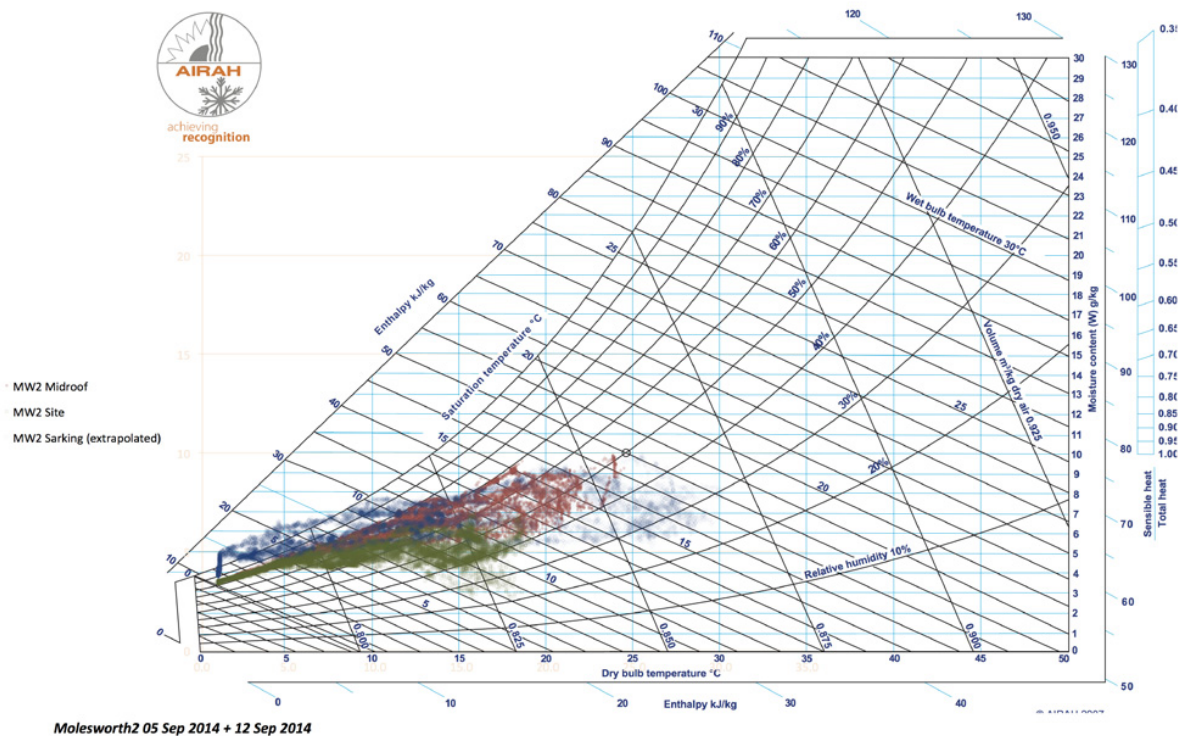


Fig. 5. Molesworth psychrometric chart.

The research team established several deficiencies from both the design and construction professions, namely:

- Site subsoil drainage was rarely considered,
- Subfloor ventilation was inconsistent,
- Most building wall wraps were vapour impermeable, not allowing high vapour content air to leave the wall system,
- Most cladding systems were not constructed with a vapour cavity, providing significant thermal bridging to the inside surface of the wall wrap,
- Many elements punctured the air barrier and vapour control layer within walls,
- Many elements punctured the air barrier and vapour control layer within the ceiling,

- Roof space ventilation was rarely considered, not allowing high vapour content air to leave the roof space.
- Roofing material and sarking were often installed in a manner which provided extensive contact between the two materials providing significant thermal bridging and condensation.

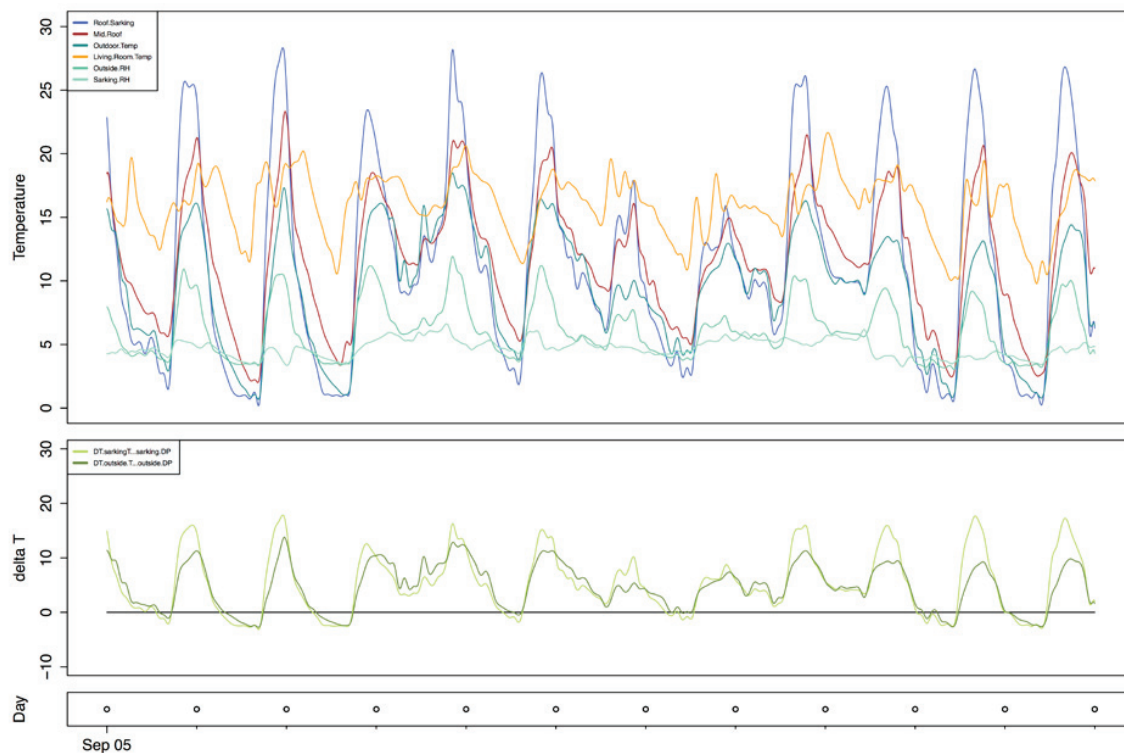


Fig. 6. Molesworth composite temperature graph.



Fig. 7. Expansion and cracking of timber due to moisture pooling at glazing.



Fig. 8. Mould growth on bearer, joist, wall batts and gaps left in wall insulation.

### 3.2. Is there a national problem?

In response to a growing national concern, the ABCB instigated a nationwide survey in late 2015 to assess the industry's perception of any condensation issues within residential and multi-residential buildings constructed in the last 15 years. The nationwide survey received one of the greatest responses ever received by the ABCB for an industry based survey. The responses did vary relative to jurisdiction however it has been established that this may have been due to industry awareness of the survey. Non-the-less, the respondents to the survey identified that up to 40% of new buildings may have a condensation problem. Furthermore, the responses through both formal acknowledgement and answers to survey questions highlighted an industry wide lack of knowledge about the causes of condensation, vapour pressure management, air tightness and the role a house owner should or should not play to manage condensation. Many respondents stated it was the home owners fault, and not that of the built fabric [14]. The mere fact that responses were received from all jurisdictions (all Australian climate types), and that most identified a concern about condensation in new buildings clearly establishes that there may be a national condensation and mould problem.

## 4. Human health

An aspect that is not fully comprehended in Australia is the impact that condensation and mould within buildings has on short and longterm occupant health. In addition to the previous images which showed mould growth, Fig. 9 and Fig. 10 below show some further examples of mould growth in new homes, less than three months old. The benefit of mould growth in Fig. 9 is that it is visible to the home owner and advice can be sought. However, the mould growth on the underside of the foil blanket sarking system, shown in Fig. 10 would often be invisible to most home owners, who rarely look into their roof spaces.

Due to the presence of mould on many surfaces in the Tasmanian houses, mould samples were taken from subfloor, occupied and roof space zones. The types of samples taken included scrapings from mould affected materials and trays placed in rooms for a period of one hour which allowed for spores settle. In both scenarios the samples were delivered to the Infection and Molecular Diagnostics Research Group, School of Human Life Sciences, University of Tasmania for incubation and identification. A range of mould genera were identified including; penicillium, zygomycete, cladosporium, and aspergillus.

The regular occurrence of relative humidity above 76% or the accumulation of moisture, on surfaces and interstitial spaces has the potential to promote mould growth that has the possibility of affecting the health of the building's occupants [32]. One of the base tenements of the National Construction Code is the protection of human health. Where mould is a concern, it should first be noted that relative humidity is only an approximate indicator of the conditions, with water activity being the more immediate indicator of when conditions are conducive for mould growth. Depending on fungal species, growth is likely when water activity exceeds 0.76 to 0.96, subject to temperature, time, and material composition [33].

However, it has been accepted internationally that damp buildings and mould growth can have a significant impact on human health [34-36]. The World Health Organisation has surmised that sufficient epidemiological evidence is available from studies conducted in different countries and under different climatic conditions to show that the occupants of damp or mouldy buildings, are at increased risk of respiratory symptoms, respiratory infections and exacerbation of asthma. There is ample research exploring correlation between wet buildings, mould and their impact on immunology and allergy [16, 17, 37-45].

Additionally, the WHO guidelines identify that correlation between dampness, microbial exposure and health effects cannot be quantified precisely, establishing that no quantitative health-based guideline values or thresholds can be recommended for acceptable levels of contamination with microorganisms. As a result, it is recommended that dampness and mould-related problems be prevented.



Fig. 9. Mould growth in carpet, wall base, skirting board and on plasterboard.



Fig. 10. Mould growth on foil backed blanket sarking system.

## 5. A regulatory perspective

Since 2003 the NCC has not changed significantly in how it identifies, describes, or regulates vapour management, condensation and mould. That is, there is no regulatory requirement to manage vapour pressure, mitigate condensation and avoid the growth mould. This lack of evolution within the NCC has the potential to significantly impact on the ability of new buildings to appropriately manage condensation risk. As the built fabric of new buildings has changed to improve thermal performance, there is a lack of a clear strategy within the NCC to manage condensation. This results in significant short comings in the management of condensation in roofs and walls. The NCC has moved out of step with a range of condensation mitigation regulations that are now standard within comparable international regulatory systems

The term moisture specifically refers to liquid moisture risk. This limited definition is out of step with international regulation and has the potential to limit the scope of understanding of risk to only liquid moisture at the exclusion of condensation. The NCC lacks clarity about vapour control layers, which restricts any strategic approach to condensation mitigation. The description of walls into a vapour control layer or into distinct planer functions the thermal, air barrier and vapour control layer functions is a standard practice in most developed nations. Additionally, clear definitions of the climatically appropriate vapour control layer is required for both the design and construction professions to enable appropriate product development and selection. The NCC has no requirement to model any component of the built envelope to establish if there is a condensation risk. The lack of such modelling restricts the ability to ensure that strategies to mitigate condensation, be they mandated or not, are achieving expected outcomes.

The NCC, as with other regularity systems, prescribes a minimum ventilation rate based on operable windows area per meter square of floor space. However, in regards to condensation and humidity control, whether the system is passive or a mechanical system is not addressed. Most regulations stipulate they must operate without the active participation of occupants. The NCC is out of step with other reviewed countries in not regulating minimum airtightness standards.

These deficiencies are in stark contrast to the extensive performance criteria within the United States, Canadian, English, European and New Zealand building regulations. The Canadian building regulation clearly articulates that it is not the building occupant's responsibility to manage condensation risk. The British building regulation refers the design and construction professions to BS5250: Code of practice for control of condensation in buildings [46].



## 6. Conclusion

This research was established to assess the state of any condensation, and subsequent mould growth, problem that may exist in new Tasmanian buildings. Since 2014, the scope of the research has expanded and in 2016, the research included the analysis of a nationwide survey established by the Australian Building Codes Board. The research conducted within Tasmania established many deficiencies and significant gaps in knowledge within all members of the design and construction professions. Aspects included vapour pressure management, built fabric ventilation needs, air tightness and thermal bridging. This research also established that buildings were ‘built to code’. Within the Tasmanian context, BSOL supported training seminars for Architects, Building Designers, Engineers, Building Surveyors and Builders, which openly discussed these matters and suggested actions to minimize condensation risk and mould growth. However, further research and training is required.

At the national level, and based on the analysis of the nationwide condensation survey, it appears that there is an industry wide awareness that condensation may be a problem in all jurisdictions and climate types in Australia. A review of the Australian National Construction Code has found it lacking in definition, guidance and requirement within the area of vapour pressure management, vapour control layers, specific ventilation requirements for cavities and roof spaces, and thermal bridging of critical elements which can promote the occurrence of condensation within the built fabric.

## Acknowledgements

This research has been made available through funded research from Building Standards and Occupational Licensing, Department of Justice, Tasmania, and the Australian Building Codes Board. Additionally, extensive national and international in-kind industry based support has been provided by CSR Building products.

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